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V-5. INTEGRATED RISK ASSESSMENT MODEL (IRAM) FOR DETERMINING WHITE PHOSPHORUS ENCOUNTER RATE BY WATERFOWL

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INTRODUCTION

Remediation managers are faced with the question of what level of clean up is sufficient to reduce risk to a target indicator species. For Eagle River Flats, emphasis has been placed on ducks in general, and mallards in particular as the indicator species, primarily because they are the most obvious victims of white phosphorus poisoning. This study focuses on developing a simple method for risk assessment for white phosphorus (WP) encounter rate by dabbling ducks feeding at Eagle River Flats. We use extant data on feeding behavior, estimates of mortality based on telemetry, and the distribution of WP in the marsh to develop this model. The utility of the model lies in its use as a management guide for remediation efforts where level of clean up can be used to predicted impact on the mortality rate of ducks using Eagle River Flats.

METHODS

Mallards are used as the receptor of choice because previous observations have indicated that this species is the most susceptible to WP poisoning (Reitsma and Steele 1994). Behavioral observation quantifying the feeding behavior of ducks was obtained from data collected by DWRC and NEILE. The data estimating the distribution of WP was obtained using data derived from Racine et al. (1993). The data estimating morality was derived from telemetry studies of Cummings et al. (1994).

A simple model for estimating the probability (risk) of encountering white phosphorus can be described by

$$M = cFW \tag{1}$$

where M is the probability of mortality, F is the proportion of time a duck spends feeding, W is the probability of encountering a WP particle, and c is a proportionality constant relating F and W. We make the following assumptions about the variables: W is assumed to be the probability of encountering a WP sediment concentration of 1 µg/g. This concentration is generally associated with visibly measurable particles of WP likely to be encountered (>1 mm, C. Racine, pers. obs.) and retained by filter feeding dabbling ducks (Kloos 1986). We make the assumption that a duck ingesting such a sample has a 100% chance of dying.

RESULTS AND DISCUSSION

If the goal is to remediate sediment to a specific level of WP, then equation (1) can be solved for W, and by rearranging

$$W = M/Fc. \tag{2}$$

To simplify matters even further we make the assumption that c = 1, i.e. that encountering a WP particle is directly proportional to the feeding effort of the receptor species. Thus, substitution for M and F will yield an estimate of a marsh-wide probability of encountering a WP particle. Based upon telemetry data Cummings et al. (1994) estimated that the probability of mortality for a resident mallard was 0.1. Two independent measures of feeding effort of mallards indicate that mallards have a probability of feeding of about 0.8. Solving for W indicates that a mallard has a marsh wide probability of 0.125 for encountering a WP particle concentration greater than 1.0 µg/g. Is this a reasonable estimate?

Racine et al. (1993) summarized the frequency of sediment samples positive for WP as a function of area of the marsh (Table V-5-1). Of the total number of

Table V-5-1. Proportion of sediment samples testing positive for WP (i.e., above the detection limit) in Eagle River Flats (adapted from Racine and Cate 1994).

Area	%
A	12
B	0
C	37
BT	72

sediment samples taken over the years, the proportion of samples testing positive for all of the marsh was 30.3%. At this stage we argue that a marsh-wide hit rate is the only relevant metric because of the high mobility of ducks. That is to say, ducks are assumed to have equal access and equal use of all sections of the marsh. How a violation of this assumption affects our estimates of risk will be discussed below. Moreover, sediment samples testing positive for WP are certainly not all equal in toxic potential. A minimum concentration must exist, and this concentration is most likely set by particle size and its probability of being retained by a duck's lamellae during filter feeding (see below). For the moment we assume that retention probabilities are unknown. At this point in the model's development we make the assumption that only sediment samples of concentrations of 1.0 μg/g are lethal. This concentration generally corresponds to the likelihood of finding a visible particle in the sample. Smaller concentrations generally are associated with dissolved WP and probably are not sufficient to be lethal (Racine, pers. comm.). Of the 30.3% WP positive samples, only 25% have concentrations higher than the threshold value (Racine et al. 1993, Racine and Walsh 1994). Thus, the estimated probability of encountering a lethal concentration of WP in the sediment, as determined by CRREL's sampling efforts, is 0.076. This value is remarkably consistent with the encounter probability calculated from the receptor mortality and feeding effort data, i.e. 0.125. Therefore, we conclude that this simple approach is sufficient to serve as general method for setting guidelines for remediation, assuming that the mallard receptor is the most sensitive receptor of the system.

There is one major caveat to be considered using the above approach in estimating risk. The risk of WP encounter is a marsh-wide estimate, integrating the WP concentration over the entire marsh and taking into account the high mobility of waterfowl. As such this model gives a general indication of the safety of the entire marsh to waterfowl. The model does not account for differential use of specific habitats, instead it assumes that ducks use all habitats with equal probability. This short-coming can be adjusted by weighing the WP concentration of a specific area by the probability that the specified area is used by ducks. Thus,

$$W = u_i W_{c,i} \tag{3}$$

where W is defined as the probability of encountering WP at a concentration greater than 1 µg/g, u is the proportion of time a duck uses habitat or area i, and $W_{c,i}$ is the proportion of sediment samples with a concentration greater than 1 u/g for area i. For a given level of acceptable mortality the model can be solved for compartmentalized values of W for any given area i to guide the remediation process. However, waterfowl use of an area is a dynamic event, influenced by ongoing remediation efforts, seed distribution, tides etc. Finally, the remediation process itself may affect long-term use of a specific area. The model assumes that u will return to pre-remediation values after clean-up is achieved. The predicted success of the clean-up is only accurate if long-term u's remain relatively stable. To the extent that this will be true is unknown.

There remains an alternative for guiding site-specific remediation. The risk of WP encounter for each site may be estimated as follows

$$E_r = SNRT \tag{4}$$

where E_r is the probability of encountering a lethal WP particle, S is the amount of sediment a duck processes per unit time, N is the number of particles per unit mass of sediment, T is the time a duck spends feeding, and R is the duck's efficiency of recovering a WP particle from the sediment.

Again we assume that sediment concentrations of WP of 1 µg/g are lethal. Concentrations at or higher than this level are associated with the presence of measurable particles of WP. Concentrations below this level are not, and are assumed to be the result of diffusion of WP into the sediment from particles (Racine, pers comm.). T is calculated as 60 s/min × 60 min/hr × # hr of daylight × F, where F is the proportion of time spent feeding. F is known to be 0.8 for mallards based upon behavioral observations. Good estimates of R are available. Kloos (1986) studied the feeding mechanics of mallards and found that the recovery efficiency for particles sized between 0.7 and 1.2 mm was 0.57. This particle size range encompasses the most common particle sizes of WP encountered in sediment (Racine et al. 1993). S is the rate that ducks pass water/sediment through their bills while feeding and was determined to be between 6–9 mL/sec (Kloos 1986). N is the number of particles of WP per mL of sediment sized greater than 0.5 mL. An acceptable encounter probability (i.e., equivalent to mortality assuming every particle is lethal) can be specified and the equation solved for N. What would need to be determined is a correlation between N and the concentration of WP (µg/mL) normally measured during sediment analysis.

FEEDING BEHAVIOR

One of the main components of risk assessment model is the amount of time a duck spends feeding while on the marsh. The amount of time feeding is related to the amount of sediment a duck is likely to process while filter feeding, hence influencing the likelihood of encountering a WP particle. Other factors may also affect feeding rate, e.g. weather conditions, habitat type, social interactions, and are the subject of more intensive analysis. However, from a broad perspective, the proportion of time spent feeding is the metric of relevance with respect to the risk assessment model.

Two methods were employed to assess feeding effort by filter feeding ducks: (1) individual focal behavior (DWRC), (2) population average (NEILE).

Individual focal behavior

Investigators would randomly select an individual duck and note prevailing weather conditions, species, location on the marsh, time, date and habitat characteristics. The duck was then monitored for its activity until the either the duck left the area or the investigator lost sight of the animal. Every 10 s the investigator would note if the duck was feeding from the substrate, making bill contact with the surface of the water, or engaged in some other activity. Behavioral observations were randomly stratified during each 2-hour sampling period for the morning (sunrise–1000 h), midday (1000–1600 h) and evening (1600–sunset). This assured that an unbiased sample with respect to time of day and the daily activity patterns of ducks would be obtained. The average proportion of time engaged in

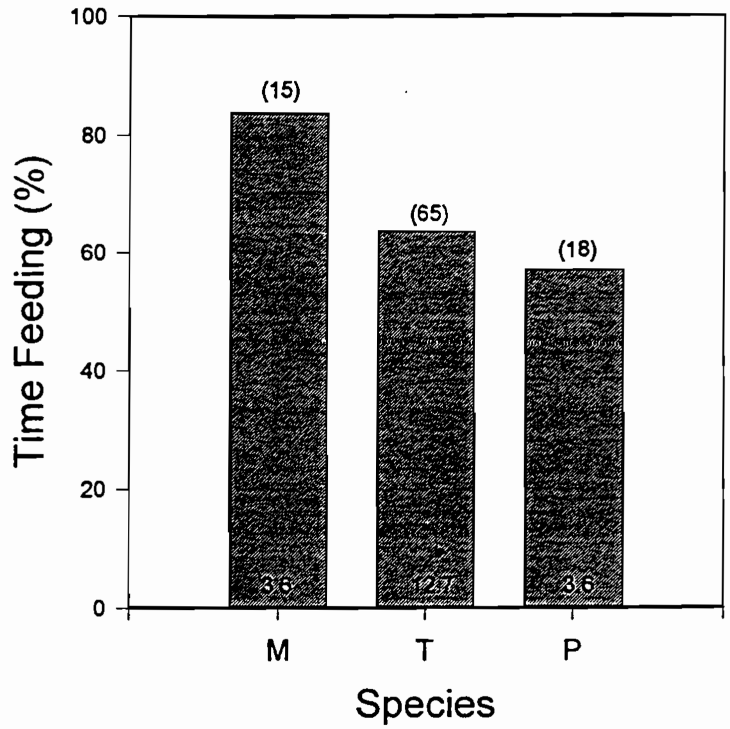

Figure V-5-1. The proportion of time waterfowl spent feeding in ponded areas (C and the C/D transition) during the fall of 1994. Numbers in parentheses represent the total number of ducks observed. Numbers within the shaded bars are the total number of hrs of observation. Species codes are M, mallard; T, green-winged teal; P, pintail. Observation were made every 10 seconds until the observer lost sight of the duck.

substrate feeding for mallards, pintails and green-winged teals was tabulated (Fig. V-5-1).

A summary of the fall data for mallard, pintail and green-winged teal is presented in Fig. V-5-1. A total of 15 mallards were observed for 3.6 hr. During the observation periods mallard fed approximately 83% of the time. A total of 65 green-winged teal were observed for 12.7 hours. During the observation periods teal fed approximately 65% of the time. A total of 18 pintail were observed for 3.6 hr. During the observation periods pintail fed 58% of the time.

Population average

The waterfowl behavior surveys were conducted during two haze-free periods, one from 18 April–3 May and the second from 12 August–5 September. The objective was to quantify feeding activity by waterfowl during periods of low human activity on the marsh. Up to four observers simultaneously recorded the precise location of individual waterfowl by placing a species and behavior code onto a map of the ponded areas being observed. Each duck was categorized as feeding, loafing, preening, or swimming. The species that were mapped included mallard, northern pintail, and green-winged teal. The number of widgeon and shovelers in the area was recorded but their locations were not mapped. Observations were made from observation towers in areas A, B, C, Racine Island (spring only) and Bread Truck Pond.

An overlay of a 100- × 100-m grid, aligned with the UTM grid was placed on these field maps and the total number of ducks in each grid cell was counted. The average number of ducks was calculated for each 1-ha cell in both spring and fall.

Table V-5-2 summarizes behavior of each species in each of four areas. In general, all ducks spent most of their time feeding (85% in spring and 74% in fall). However, there was an 11% decrease from spring to fall which might be explained by the potentially higher physiological stresses during spring, i.e., lower temperatures and greater energy demands resulting from having recently migrated long distances.

Table V-5-2. Percent of ducks, feeding by area and season in 1994.

	Spring				*Fall*			
Area	*MA*	*PT*	*GWT*	*Tot*	*MA*	*PT*	*GWT*	*Total*
A	80	88	90	88	76	87	68	76
B	78	91	77	81	65	89	70	70
C	68	63	86	84	100	-	92	92
BTP	80	84	86	85	89	73	73	74
Total	74	83	86	85	69	87	73	74

CONCLUSIONS

The confidence a manager will have in setting standards for WP remediation is only as good as the accuracy of the estimates for feeding behavior, duck mortality and WP distribution and concentration. While we are hopeful that the model presented will be of utility in easily setting remediation standards, justification for its use needs a more careful analytical review of the telemetry and WP distribution data. This can be accomplished without impeding operational requirements or requiring additional field work. We feel that the accuracy of the feeding data are adequate and no further attention to this variable is warranted. However, we do recommend that continued telemetry data and/or mortality transects be gathered for mallard and teal. These data are critical to empirically document the consequences to mortality of any potential clean-up efforts. Similarly, WP sampling after remediation of an area is need to validate the clean-up effort and for use in correlating the WP concentration to subsequent mortality estimates.

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